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Discrete element modelling of granular materials incorporating realistic particle shapes

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Abstract

This paper proposes an approach to generate realistic particle shapes considering the major plane of orientation of particles in discrete element modelling (DEM). The particle generation framework includes capturing high-quality scanning electron microscope (SEM) images, followed by image processing and generation of clumps using a commonly used multi-sphere (MS) approach in particle flow code (PFC3D). A set of experimental direct shear tests (DST) and subsequent DEM simulations were performed by incorporating realistic particle shapes. The simulation results show a good agreement with those obtained in the laboratory. In addition, the normal stress showed a significant effect on the structural anisotropy of the granular materials.

Keywords: Discrete element method, Direct shear test, Subnetworks, Clumped particles

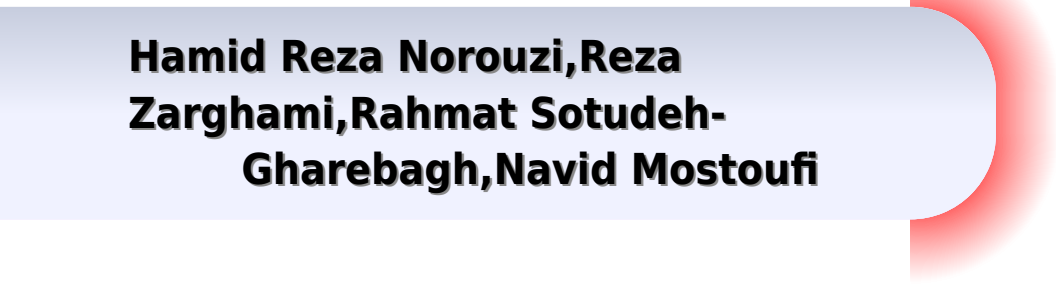
Introduction

Morphological features of granular materials have attracted many researchers in the field (e.g., [1, 2]); [3, 4]. It was evident from the experimental investigations that the mechanical behaviour of granular materials including compressibility, shear strength, dilation, and crushability, was highly influenced by the morphological features (e.g., [5–9]). However, performing laboratory tests is time-consuming and may not be feasible to relate the morphological features of realistic particles.

For continuum-based numerical methods such as finite-element or finite difference methods, the physics occurring at the grain scale is difficult to capture because of its discrete nature and may not be possible to explore microscale insights. On the other hand, the discrete element method (DEM) pioneered by Cundall and Strack [10] has progressed rapidly over the decades and is now capable to capture microscale response of granular materials (i.e., fabric orientations, force chain networks and associated displacement vectors) considering realistic particle shapes. Using DEM, several researchers have considered different traditional element tests, such as triaxial (e.g., [1, 4, 11–14]) and direct shear tests (DST) (e.g., [15–19]) to explore the microscopic responses of granular materials. In general, to incorporate the particle shape effect into DEM, one can adopt either of the two approaches that are commonly used. The earlier one is to introduce a rheology-type rolling resistance contact law between the particles, while the latter one is

Discrete Element Modeling Of Granular Materials

**Hamid Reza Norouzi, Reza
Zarghami, Rahmat Sotudeh-
Gharebagh, Navid Mostoufi**



Discrete Element Modeling Of Granular Materials:

Discrete-element Modeling of Granular Materials Farhang Radjai, Frédéric Dubois, 2011-05-03 This book brings together in a single volume various methods and skills for particle scale or discrete element numerical simulation of granular media. It covers a broad range of topics from basic concepts and methods towards more advanced aspects and technical details applicable to the current research on granular materials. Discrete element simulations of granular materials are based on four basic models: molecular dynamics, contact dynamics, quasi static and event driven, dealing with frictional contact interactions and integration schemes for the equations of dynamics. These models are presented in the first chapters of the book, followed by various methods for sample preparation and monitoring of boundary conditions as well as dimensionless control parameters. Granular materials encountered in real life involve a variety of compositions, particle shapes and size distributions and interactions: cohesive, hydrodynamic, thermal, that have been extensively covered by several chapters. The book ends with two applications in the field of geo materials. *Discrete Element Modeling of Granular Materials Under Biaxial Conditions* Runing Zhang, 1996 *Particle in Cell and Discrete Element Models for Granular Materials*, 2001

Understanding the Discrete Element Method Hans-Georg Matuttis, Jian Chen, 2014-05-12 Gives readers a more thorough understanding of DEM and equips researchers for independent work and an ability to judge methods related to simulation of polygonal particles. Introduces DEM from the fundamental concepts: theoretical mechanics and solidstate physics with 2D and 3D simulation methods for polygonal particles. Provides the fundamentals of coding discrete element method DEM requiring little advance knowledge of granular matter or numerical simulation. Highlights the numerical tricks and pitfalls that are usually only realized after years of experience with relevant simple experiments as applications. Presents a logical approach starting with the mechanical and physical bases followed by a description of the techniques and finally their applications. Written by a key author presenting ideas on how to model the dynamics of angular particles using polygons and polyhedral. Accompanying website includes MATLAB Programs providing the simulation code for two dimensional polygons. Recommended for researchers and graduate students who deal with particle models in areas such as fluid dynamics, multi body engineering, finite element methods, the geosciences and multi scale physics. **Discrete Element Method to Model 3D Continuous Materials** Mohamed Jebahi, Damien Andre, Inigo Terreros, Ivan Iordanoff, 2015-02-26 Complex behavior models: plasticity, cracks, visco elasticity face some theoretical difficulties for the determination of the behavior law at the continuous scale. When homogenization fails to give the right behavior law, a solution is to simulate the material at a meso scale in order to simulate directly a set of discrete properties that are responsible of the macroscopic behavior. The discrete element model has been developed for granular material. The proposed set shows how this method is capable to solve the problem of complex behavior that are linked to discrete meso scale effects. **Discrete Element Models for Granular Materials and Rock Masses** Ricardo E. Barbosa-Carrillo, 1990 Discrete element methods DEMs are a family of

related numerical procedures for solving problems that exhibit gross discontinuous behavior. Many of these methods are capable of analyzing multiple interacting bodies undergoing large displacements and rotations. These methods are suitable for studying several types of geotechnical problems involving granular materials and rock masses which are intractable with conventional methods based on continuity assumptions. Even though DEMs have been used for about twenty years and interest in the use of these techniques is increasing rapidly, the methodology has not progressed significantly and most DEMs for geomechanical materials still require unrealistic idealizations. In fact, most models for granular materials still represent individual particles as two-dimensional circular disc elements. Methods for the analysis of jointed rock are still unable to adequately model the deformability of the individual blocks and cannot incorporate the effects of water pressures along the joints. In all these methods, interactions among elements are specified through the same point contact models which are unrealistic in many applications. In addition, there has been no significant improvements in the schemes for detection of contacts, which is the most expensive part of DEM analysis. In this research, a series of two-dimensional and three-dimensional DEMs have been developed to model the discontinuous behavior of granular materials and rock masses. A total of five DEMs were proposed along with new block models, contact models, and effective contact detection procedures and data structures which allow analyses with large numbers of blocks. Granular materials have been represented by large numbers of rigid particles of random shapes and sizes. Rock masses have been modeled as assemblages of multiple deformable rock blocks interacting through deformable joints. The considerable experience gained in the finite element method to model continuum has been utilized to model the deformability of individual blocks. Realistic distributed contact models have been proposed. Discrete methods have been developed which model the discontinuous character of water flow through rock masses and the effects of water pressures along rock joints. Individual rock blocks have been assumed to be impervious. Fluid flow has been assumed to occur through the joints. The proposed hydromechanical model includes the coupling between flow and deformation.

Uncertainty Quantification of the Homogeneity of Granular Materials Through Discrete Element Modeling and X-ray Computed Tomography Patrick Noble, 2012. Previous research has shown that the sample preparation method used to reconstitute specimens for granular materials can have a significant impact on its mechanistic behavior. As the Discrete Element Method becomes a more popular choice for modeling multiphysics problems involving granular materials, the sample heterogeneity should be correctly characterized in order to obtain accurate results. In order to capture the effect of sample preparation on the homogeneity of the sample, standard procedures were used to reconstitute samples composed of a homogeneous granular material. X-ray computed tomography and image analysis techniques were then used to characterize the spatial heterogeneity of a typical sample. The sample preparation method was modeled numerically using the Discrete Element program PFC3D. The resulting microstructure of the numerical sample was compared to the results of the image analysis to determine if the heterogeneity of the sample could be reproduced correctly for use in Discrete Element Modeling.

The Discrete Element Method for Granular Solids Bruno Chareyre, 2029-12-15 The Discrete Element Method for Granular Solids provides scientists and engineers with solutions to the basic problems of DEM modeling of granular solids both conceptual and practical To help new users the book carefully follows important steps from conceptual model to the numerical simulation of dense granular materials This includes contact models numerical schemes simulation setup and post processing The authors present many examples including the complete code which assists the reader in reproducing the simulations with open source code Yade DEM that was developed by the author and his colleagues at the University of Grenoble Presents the basics along with effective usage of DEM code Details state of the art practical implementation for research and numerical methods Provides examples with scripts linking the book to online content and freely available software [yade dem org](http://yade-dem.org)

Mesoscale Models Sinisa Mesarovic, Samuel Forest, Hussein Zbib, 2018-11-19 The book helps to answer the following questions How far have the understanding and mesoscale modeling advanced in recent decades what are the key open questions that require further research and what are the mathematical and physical requirements for a mesoscale model intended to provide either insight or a predictive engineering tool It is addressed to young researchers including doctoral students postdocs and early career faculty

Discrete Element Method for Multiphase Flows with Biogenic Particles Ling Zhou, Mahmoud A. Elemam, Ramesh K. Agarwal, Weidong Shi, 2024-09-24 This book presents the advanced theory and application of the combined Computational Fluid Dynamics Discrete Element Method CFD DEM to multiphase flow simulations of the gas and bio particulate matter of non uniformly shaped biomass It explores how DEM can simulate the complex behaviour of biomass particles such as their packing in the multiphase flows that occurs in the agricultural product processing industries It offers an overview of aerodynamic systems such as cyclone separators used in the agricultural processing industry A detailed description of DEM modeling including the particle particle particle boundary and particle fluid interactions in the context of biomass particles of varying sizes and shapes is provided Coverage includes the critical application of CFD DEM simulation technology in designing and optimizing grain handling and processing equipment and the application of extended DEM to other granular flows of complex particles like sand powders and dust from mines where clumping and agglomeration occur The application of DEM in modeling and simulation of complex multiphase systems can help improve productivity reduce costs and increase efficiency in the agricultural industry

Modeling of Materials and Its Applications in Advanced Technologies C. H. Chu, 2002 This book contains the proceedings of Symposium L of the International Conference on Materials for Advanced Technologies held from the 1st to the 6th of July 2001 in Singapore The aim of this important meeting was to bring together researchers and engineers having very different backgrounds and thus promote free discussion and the exchange of ideas across many interdisciplinary boundaries

Advanced Rail Geotechnology - Ballasted Track Buddhima Indraratna, Wadud Salim, Chalachat Rujikiatkamjorn, 2011-03-16 Ballast plays a vital role in transmitting and distributing train wheel loads to the underlying sub

ballast and subgrade Bearing capacity of track train speed riding quality and passenger comfort all depend on the stability of ballast through mechanical interlocking of particles Ballast attrition and breakage occur progressively under heavy cyc

Granular Dynamics, Contact Mechanics and Particle System Simulations Colin Thornton, 2015-09-03 This book is devoted to the Discrete Element Method DEM technique a discontinuum modelling approach that takes into account the fact that granular materials are composed of discrete particles which interact with each other at the microscale level This numerical simulation technique can be used both for dispersed systems in which the particle particle interactions are collisional and compact systems of particles with multiple enduring contacts The book provides an extensive and detailed explanation of the theoretical background of DEM Contact mechanics theories for elastic elastic plastic adhesive elastic and adhesive elastic plastic particle particle interactions are presented Other contact force models are also discussed including corrections to some of these models as described in the literature and important areas of further research are identified A key issue in DEM simulations is whether or not a code can reliably simulate the simplest of systems namely the single particle oblique impact with a wall This is discussed using the output obtained from the contact force models described earlier which are compared for elastic and inelastic collisions In addition further insight is provided for the impact of adhesive particles The author then moves on to provide the results of selected DEM applications to agglomerate impacts fluidised beds and quasi static deformation demonstrating that the DEM technique can be used i to mimic experiments ii explore parameter sweeps including limiting values or iii identify new previously unknown phenomena at the microscale In the DEM applications the emphasis is on discovering new information that enhances our rational understanding of particle systems which may be more significant than developing a new continuum model that encompasses all microstructural aspects which would most likely prove too complicated for practical implementation The book will be of interest to academic and industrial researchers working in particle technology process engineering and geomechanics both experimentalists and theoreticians

Discrete Element Modeling of the Influences of Density and Confining Pressure on the Compression and Shear Behavior of Granular Materials Andrew Joseph Walsh, 1998 International Conference on Advances in the Theory of Ironmaking and Steelmaking (ATIS 2009), December 09-11, 2009 Govind S. Gupta, M. R. Lollchund, 2009 Contributed articles presented in the International Conference on Advances in the Theory of Ironmaking and Steelmaking organized by the Dept of Material Engineering IISc Bangalore

Behaviour of Granular Materials Bernard Cambou, 2014-05-04 This book presents a complete and comprehensive analysis of the behaviour of granular materials including the description of experimental results the different ways to define the global behaviour from local phenomena at the particle scale the various modellings which can be used for a D E M analysis to solve practical problems and finally the analysis of strain localisation The concepts developed in this book are applicable to many kinds of granular materials considered in civil mechanical or chemical engineering

Computational Mechanics of Arbitrarily Shaped Granular Materials Siqiang Wang, Shunying

Ji,2024-01-17 This book focuses on discrete element methods for arbitrarily shaped granular materials including super quadric models spherical harmonic functions and level set methods and numerical analysis of the flow characteristics of non spherical granular materials This book is used as a reference book for scientific researchers engaged in dynamic analysis of granular materials and optimal design of equipment structures in the fields of engineering mechanics applied physics mechanical engineering and chemical engineering as well as for graduate students or senior undergraduates of related majors in institutions of higher education **Practice of Discrete Element Method in Soil-Structure Interface Modelling** Wan-Huan Zhou,Zhen-Yu Yin,2022-08-12 This book is related to a parametric study of the soil structural interface shearing behavior based on the numerical simulations of interface shear test with DEM which is conducted from the role of soil properties particle properties and structural properties To aid readers in easily understanding the generation implementation of models and controlling modes for each part the relevant code is provided in the text and the whole source code of model is given in Appendix to share with readers for practice The book is intended for graduate level teaching and research in soil mechanics and geotechnical engineering as well as in other related engineering specialties This book is also of use to industry practitioners due to the inclusion of real world applications opening the door to advanced courses on modeling within the industrial engineering and operations research fields *Coupled CFD-DEM Modeling* Hamid Reza Norouzi,Reza Zarghami,Rahmat Sotudeh-Gharebagh,Navid Mostoufi,2016-10-17 Discusses the CFD DEM method of modeling which combines both the Discrete Element Method and Computational Fluid Dynamics to simulate fluid particle interactions Deals with both theoretical and practical concepts of CFD DEM its numerical implementation accompanied by a hands on numerical code in FORTRAN Gives examples of industrial applications *Discrete Element Method for Modeling Solid and Particulate Materials* Federico A. Tavarez,2005

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